



Gray Calibration of Digital Cameras to Meet NIST Mugshot Best Practice

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Abstract

A primary objective of any process of photography, electronic publishing, or printing is to reproduce all colors as perfectly as possible. A good starting point is to render a series of known shades of gray as accurately as possible. The goal of this experiment is to show how digital camera images can be calibrated to meet the NIST "Best Practice Recommendation for the Capture of Mugshots"¹ (BPR) Document. This paper represents the results of a two-part experiment that was conducted to determine the best methodology for calibrating digital cameras for rendering gray images as close to the eighteen percent gray intensity level, specified for background color in the BPR document. The first part of the experiment was conducted to determine the characteristics of the specific cameras used in the experiment by measuring the rendered version of various known gray intensity levels and determining the amount of non-linearity among the quantified gray samples. The second part of the experiment was a measurement of the effect that different colored clothing had on the rendered gray background for each of the three digital cameras used in the experiment. Results for three specific digital cameras are presented to illustrate the methods involved. These results will soon be out of date, because the technology is changing very rapidly.

Introduction to Color Electronic Imaging

The basic goal of photography, either film-based or digital, is to record a permanent image by capturing light reflected from a subject. In this experiment, several digital still cameras were used to capture images of gray test samples and mugshots against a gray background. These images were taken in an otherwise unlighted laboratory using lights with different intensity and color. The interpretation of the experimental results requires that the details of the digital image capture process be described by a physical model which is more complex than the simple three color models, RGB or CYMK, that are used to record and display the digital image in the computer.

¹ The NIST "Best Practice Recommendation for the Capture of Mugshots" document can be found at the NIST Web site with the link: http://www.nist.gov/itl/div894/894.03/face/bpr_mug3.html

The experiment was further complicated by the fact that the CCD sensors used in these cameras were in part developed for applications where the goal was to produce imaging technology that was more sensitive than human vision; the cameras used here demonstrated this effect. The model is similar to the one that would be needed to characterize conventional color photography. The principal difference is in the capture process inside the camera. Techniques have been developed to insure consistent color quality for film-based image capture but these techniques are more complex than those presently in use for digital mugshot capture.

The physical processes that interact to generate the digital image are shown in Figure 1. Light from the three lamps, shown in the upper right of the figure, shines on

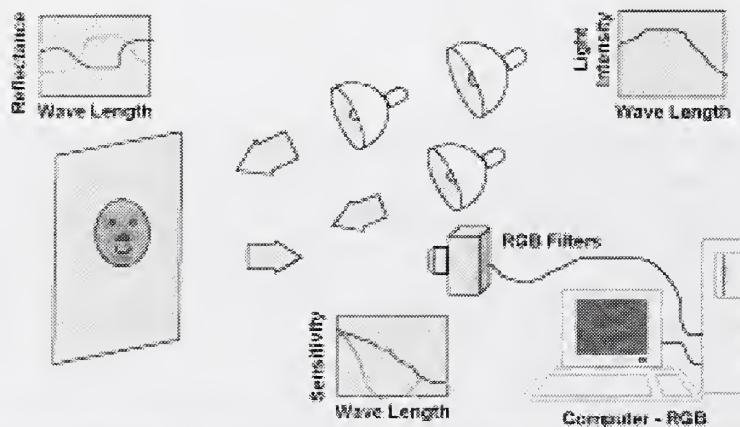


Figure 1 - Setup for Digital Image Capture

the subject shown on the left side of the figure and is captured by the digital camera connected to a computer shown in the lower right of the figure. Each of the processes relative to digital image capture is characterized by a wavelength dependent response, which affects the intensity of the light that is used by the camera to generate the final three-color image.

The lights have a wavelength dependent intensity illustrated by the graph in the upper right near the lamps. The shape of this curve affects all other aspects of the experiment and is controlled primarily by the color temperature of the lamps. The way a user can effect this color distribution is by the choice of light source. As the lamps age the intensity of illumination may also decrease.

The light from the lamps shines on the subject where it is reflected by two components, the gray background and the face of interest, which is illustrated by the blue mask. When the mask is removed from the camera field of view, the amount of light reflected by the background is a function of wavelength shown the black curve on the reflectance verses wavelength curve on the left-hand side of the figure. When the blue mask is in the field of view, the reflectance of the mask is illustrated by the blue curve in the graph. The mask does not affect the reflectance of the background. This should also be true for the digital image acquired by the computer, but, as we will discuss later, many

low-end digital cameras contain automatic exposure controls, which adjust all exposures in a way that is dependent on the specific subject being imaged.

The camera captures the light from the subject. In the capture process, the three images are formed on a CCD array through red, green, and blue (RGB) color filters. One or more CCDs are used for the filtered images and the CCD has a wavelength dependent sensitivity which is illustrated by the black curve shown in the graph in the bottom center of the figure. This sensitivity is further changed by the three color filters illustrated by the red, green, and blue curves on the graph. The experiment presented here was carried out with digital cameras that have different color sensitivities. The measured sensitivity to light of different colors is the combined effect of the CCD sensor and the color filters used to generate the three-color image. Different digital cameras are manufactured using different CCD chips that have different wavelength sensitivity. These cameras also have color filters for three-color image separation that vary from one manufacture to another. This generates different color rendering in the final digital image which is similar to using different film types in film based cameras.

A user has a reasonably good chance of controlling the light intensity and of controlling the color temperature, thus affecting the uniform gray background reflectance. The internal parameters of different digital cameras are not under user control and are not specified by the camera manufacturers. The goal of this experiment is to use the factors that are under user control to measure the effect of unknown camera characteristics on the quality and uniformity of digital mugshot images.

Mugshot Problem

Both the BPR and the Mugshot Uniformity Guidelines states that a background of 18% gray intensity is required for mugshots. The physical background can be produced with little difficulty, especially if a standard 18% gray card (obtained from Eastman Kodak² or other company involved in color standards) is available for a basis of comparison. The problem arises when a camera is used to render an image containing this background. The resultant image may or may not appear to have the same gray intensity level as the actual physical background. The resulting intensity value of the gray background will fluctuate due to various lighting conditions, exposure settings, CCD characteristics, clothing worn by the subject, etc. The problem becomes one of finding the best methodology to determine the appropriate camera settings to yield a rendering of the background that comes as close to the 18% gray as possible.

² Certain commercial imaging equipment or imaging software may be identified in order to adequately specify or describe the subject matter of this work. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the equipment or software identified is necessarily the best available for the purpose.

Constraints

The experiment was constrained to the use of digital cameras and the resultant digital images. We used a windowless office supplied with a constructed background that was painted to produce an eighteen-percent gray reflectance. We generated a set of twelve rectangular gray patches printed on letter-sized paper using the Adobe PhotoShop 4.0 software package. These gray patches were set at gray levels of 100 to 155 (on a scale of 0 to 255 where 0 represents total black and 255 represents total white) varying by five units of gray level for each gray patch. The reflectance of each gray patch was measured using a Macbeth color densitometer. This measurement allows the reflectance of the different gray samples to be compared using a method independent of the method used to generate the samples.

Equipment Used for the Experiment

1. Camera #1 - 640x480 pixel resolution with fully automatic exposure control. The JPEG compression ratio was calculated to be approximately 24 to 1. The EV settings ranged from +1.5 to -1.5 in incremental steps of 0.5. The lens had a zoom ratio of 10x.
2. Camera #2 - 1024x768 pixel resolution with fully automatic exposure control. The JPEG compression ratio was calculated to be approximately 8 to 1. The EV settings ranged from +2.0 to -2.0 in incremental steps of 0.5. The lens had a zoom ratio of 3x.
3. Camera #3 - 1200x950 pixel resolution with both automatic exposure control and manual shutter and aperture override control. Compression was not used by this camera, and the lens could be zoomed from 50 mm to 80 mm focal length.
4. Tripod
5. Three floodlights
6. Photographic light meter
7. 18% reflectance gray backdrop wall
8. Macbeth color densitometer
9. PC with Adobe PhotoShop 4.0 installed
10. Epson 800 Color Stylus Inkjet Printer

Procedures Followed

A series of steps were followed for setting up the gray calibration experiment. These steps were as follows:

STEP 1: We prepared a set of 12 gray patches, one patch per image with the dimensions 19 cm by 25.4 cm for each image. Using Adobe's PhotoShop Version 4, the gray patches were set to varying gray levels from 100 to 155 with a delta of 5 gray level units between each gray patch. Each image was checked for accuracy by using the PhotoShop luminosity histogram function. Figure 2 is an example of a gray patch image with RGB values of 125, 125, and 125 respectively.

STEP 2: Each gray patch image was printed out on the Epson 800 Color Stylus ink jet printer using Epson's² special photographic quality A4 sized paper with the highest resolution setting of 1440 dpi. A first set of images was printed using the color setting, and a second set was printed using the black only setting.

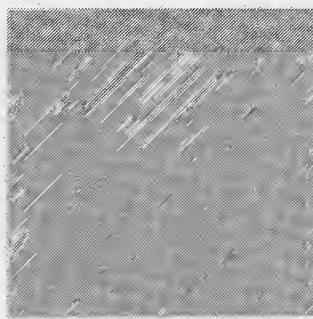


Figure 2- Sample 18% Gray Patch

STEP 3: The output pictures from the Epson printer were then measured for gray density using a Macbeth Densitometer. Five measurements were taken at each of the four corners and the middle of each printed gray patch. The average value was then calculated for each gray patch. Table 1 shows all the densitometer average readings taken from the gray patch pictures along with the readings taken from the standard 18% gray card supplied by Kodak. Readings were taken for both the color setting and the "black-only" setting on the Epson printer. Through the use of the densitometer, we determined that the "black-only" setting gave results that most closely matched the Kodak gray Card density value. Figure 3 depicts the linear variation for the "black only" density readings as shown in Table 1. This result agreed with a visual comparison, more specifically, the 125 gray level value had a density value of 0.76 compared to the Gray Card value of 0.75.

Table 1 - Macbeth Densitometer Readings

Gray Level Value	Color Print Density	Black Only Print Density
100	0.63	1.00
105	0.60	0.95
110	0.59	0.89
115	0.56	0.85
120	0.54	0.80
125	0.52	0.76
130	0.51	0.74
135	0.48	0.69
140	0.45	0.67
145	0.43	0.64
150	0.40	0.61
155	0.37	0.59
Kodak Gray Card		0.75

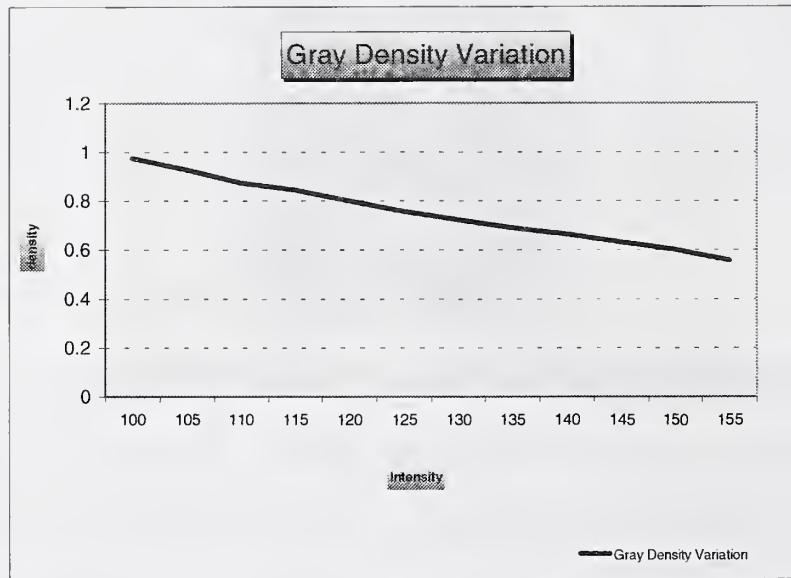


Figure 3 - Gray Density Variation vs. Intensity

STEP 4: The standard Density - Opacity Table as shown in Table 2 below was used as a basis of comparison for the values obtained from the Macbeth densitometer.

Table 2 - Density/Opacity

(Relating Transmission or Reflectance to Density)

Density (Log)	Opacity (Number)	Transmission or Reflectance
0.00	1.00	1.00
0.05	1.12	0.89
0.10	1.26	0.80
0.15	1.41	0.71

Density (Log)	Opacity (Number)	Transmission or Reflectance
0.20	1.59	0.63
0.25	1.78	0.56
0.35	2.24	0.45
0.45	2.82	0.36
0.50	3.16	0.32
0.55	3.55	0.28
0.60	3.98	0.25
0.65	4.47	0.22
0.70	5.01	0.20
0.75	5.62	0.18
0.80	6.31	0.16
0.85	7.08	0.14
0.90	7.94	0.126
0.95	8.91	0.112
1.00	10.0	0.100
1.05	11.2	0.089
1.10	12.6	0.080
1.15	14.1	0.071
1.20	15.9	0.063
1.25	17.8	0.056
1.30	20.0	0.050
1.35	22.4	0.045
1.40	25.1	0.040
1.45	28.2	0.036
1.50	31.6	0.032
1.55	35.5	0.028
1.60	39.8	0.025
1.65	44.7	0.022
1.70	50.1	0.020
1.75	56.2	0.018
1.80	63.1	0.016
1.85	70.8	0.014
1.90	79.4	0.0126
1.95	89.1	0.0112
2.00	100	0.0100
2.05	112	0.0089
2.10	126	0.0080
2.15	141	0.0071
2.20	159	0.0063
2.25	178	0.0056
2.30	200	0.0050
2.35	224	0.0045
2.40	251	0.0040

Density (Log)	Opacity (Number)	Transmission or Reflectance
2.45	282	0.0036
2.50	316	0.0032
2.65	447	0.0022
2.75	562	0.0018
2.80	631	0.0016
2.85	708	0.0014
2.90	794	0.0012
2.95	891	0.0011
3.00	1,000	0.0010
4.00	10,000	0.0001

STEP 5: From Table 2 above, the "black-only" print density readings were more closely aligned with the readings taken from the Kodak gray Card. In fact, gray level values between 125 and 130 were the best match with the average value taken from the gray card. Therefore, the "black-only" printed gray patch images were used for the photographic calibration experiment.

STEP 6: A windowless studio laboratory was used to conduct this experiment. The only permanent lighting in the laboratory was from two rows of fluorescent lights suspended from an off-white textured ceiling. The walls in the laboratory were yellowish cream color.

STEP 7: The gray patch sheets were then mounted on the 18% gray background wall in three rows of four sheets in each row starting with the lowest reflectivity sheet (100) and

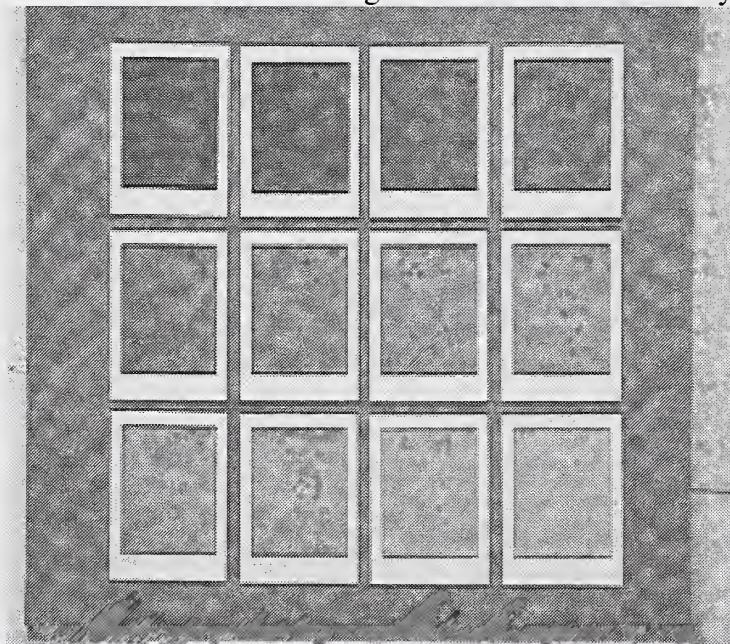


Figure 4- Gray Background Setup

ending with the highest reflectivity sheet (155) with approximately 2.54 cm (one inch) of space between each sheet. Figure 4 shows a picture of the backdrop setup with the gray patch sheets arranged in a three by four array.

STEP 8: Three photoflood lights were used in the experiment. In the initial setup, Sylvania Photo-ECA white bulbs were used with a rating of 250 watts, 120 volts and a luminescence of 3200 °K. The placement of the photoflood lights is shown in Figure 5 below. In the secondary setup, General Electric 115-120 watt blue tinted bulbs were used in place of the white bulbs to reduce the amount of red bias in the digital CCDs within each camera.

STEP 9: The two front floodlights were set six feet off the floor and initially angled inward roughly 15 degrees from the straight to back wall position with no tilt. The center back floodlight was positioned eight feet off the floor and pointed toward the ceiling at an angle of 60 degrees from the horizontal. This was done in an attempt to spread the light evenly over the surface of the backdrop. A light meter was then used to more finely adjust the lights. An attempt was made to get the light meter readings within $\pm 5\%$ over the backdrop area included in the image frame.

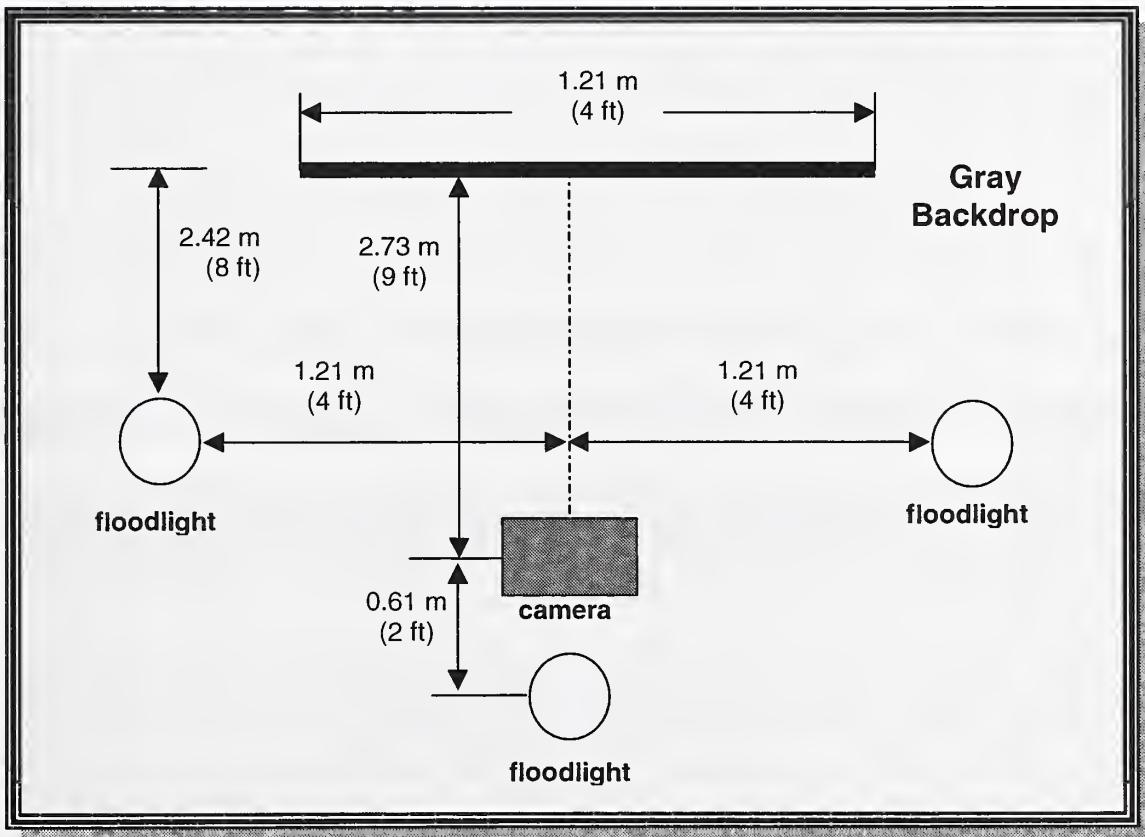


Figure 5 - Mugshot Studio Setup

129	132	132	132	131	126
130	122	144	160	177	126
130	114	134	153	171	126
129	110	125	147	163	125
129	130	130	130	129	

Figure 6 - Gray Level Values with Overhead Lights

130	131	131	130	
130	122	144	160	177
130	115	135	154	173
128	111	126	148	164
128	129	129	129	128

Figure 7 - Gray Level Values without Overhead Lights

STEP 10: Using Camera #1, set at the exposure value of 1.0 EV, Field, the highest quality JPEG compression setting, and zoomed to include the edges of the backdrop, a picture was taken with the floodlights turned on and positioned as described in STEP 9. The resultant picture was then opened in Adobe PhotoShop 4.0 and tested for mean gray level values for each gray patch and various areas of the gray background. Figure 6 illustrates the mean luminosity histogram values taken with the overhead fluorescent lights on. Figure 7 illustrates the mean luminosity histogram values taken with the

overhead fluorescent lights off.

It is evident from the two figures, shown above, that there was very little difference between the picture without the overhead lights and the picture with the overhead lights. Therefore, one may conclude that overhead lights had no significant effect on the rendered image when the photoflood lights were used. It should also be pointed out that the floodlights had a slight imbalance; i.e., brighter on the left side and darker on the right side. Figures 6 and 7 show a maximum difference of 4 gray level units when comparing the gray level values of the gray background on the left and right sides of the gray patch array. After adjusting the lights by using the light meter, Figures 6 and 7 represent the best settings achieved.

Tests Performed

As described in the diagram in Figure 5 above, photographs were taken of the twelve gray patch sheets (shown in Figure 4) using the following test scenarios.

Camera #1, Gray Background Test #1

1. Camera #1 constant camera settings: *Frame and Fine (higher resolution than normal)*
2. EV (exposure value offset) settings were varied from: *-1.5 to +1.5 and varying the steps by 0.5*
3. Photoflood lights were positioned as indicated in Step 10 above using the Sylvania Photo-ECA white bulbs with a rating of 250 watts, 120 volts and a luminescence of 3200 °K. All three floodlights were pointed towards the image frame to maximize the light intensity.

Table 3 shows the empirical data results obtained from Adobe's PhotoShop 4.0 for overall gray level intensity values and related values for the red, green and blue channels.

Table 3 - Results for Camera #1, Test #1

EV	Channel	TL	ML	BL	TR	MR	BR	100	105	110	115	120	125	130	135	140	145	150	155
-1.5	Intensity	44	43	41	46	44	40	35	39	42	43	43	47	51	53	51	54	57	59
	red	48	47	44	50	47	43	43	46	50	51	51	56	59	61	59	62	65	67
	green	43	42	40	44	43	38	31	34	37	38	39	43	46	48	46	50	53	55
	blue	38	37	34	40	38	35	37	40	43	45	43	47	51	52	50	54	57	61
-1	Intensity	52	51	46	53	52	46	42	45	49	51	51	56	60	63	60	64	69	72
	red	57	55	51	58	56	50	50	55	59	60	60	65	69	72	70	74	78	81
	green	51	50	45	52	51	44	37	40	43	45	46	51	55	58	55	59	64	67
	blue	46	44	40	48	46	40	42	46	50	52	51	56	60	63	61	65	70	73
-0.5	Intensity	62	61	55	64	62	54	49	54	58	61	62	69	74	78	74	80	85	88
	red	69	67	61	71	62	60	60	65	70	74	73	80	85	89	85	91	96	99

EV	Channel	TL	ML	BL	TR	MR	BR	100	105	110	115	120	125	130	135	140	145	150	155
0	green	62	60	54	62	62	53	43	47	52	55	56	63	68	72	68	74	79	83
	blue	56	55	48	58	57	49	43	56	60	64	64	70	74	80	75	82	87	90
	Intensity	79	78	69	82	80	70	60	67	74	79	78	86	92	96	92	100	104	109
	red	85	83	76	88	86	76	74	82	89	93	92	100	105	110	106	113	118	122
	green	77	76	67	80	79	68	53	60	66	71	71	80	85	89	85	93	97	102
	blue	71	71	62	76	74	63	62	68	76	82	80	89	94	100	95	102	108	113
0.5	Intensity	97	96	87	99	97	86	76	83	90	95	95	105	110	113	111	116	122	127
	red	104	102	94	106	103	93	91	99	106	110	110	119	125	128	125	131	138	141
	green	95	94	85	97	96	83	68	75	82	87	88	97	102	106	103	109	115	119
	blue	88	86	78	90	89	78	76	85	92	96	95	105	111	116	112	117	123	128
	Intensity	115	114	106	117	117	106	94	103	110	113	114	124	132	136	132	141	149	153
1	red	123	121	114	125	122	113	110	120	127	131	131	140	147	152	148	156	164	169
	green	113	112	104	116	115	104	85	94	101	104	105	116	122	128	124	132	140	145
	blue	105	105	96	109	107	96	96	105	112	117	116	125	133	139	133	142	150	156
	Intensity	148	148	135	151	151	136	121	132	142	147	148	161	169	181	170	178	183	185
	red	157	155	144	161	158	144	141	153	163	168	168	180	189	194	189	197	201	204
1.5	green	146	146	133	149	149	134	111	121	130	137	138	151	158	165	160	168	173	176
	blue	135	135	122	139	138	124	123	133	143	150	149	161	169	174	170	176	181	185

Key:

TL = Top Left Background
 ML = Middle Left Background
 BL = Bottom Left Background
 TR = Top Right Background
 MR = Middle Right Background
 BR = Bottom right Background
 EV = Camera #1² Exposure Value

Sony Camera #1, Gray Background Test #2

4. Camera #1 constant camera settings: *Frame and Fine* (specific settings on camera #1). The fine setting indicated a JPEG compression setting of approximately 24 to 1, and the frame setting was an enhanced mode to be used with a tripod.
5. EV settings were varied from: *-1.5 to +1.5 and varying the steps by 0.5*
6. Photoflood lights were positioned as indicated in Step 10 above using the Sylvania Photo-ECA white bulbs with a rating of 250 watts, 120 volts and a luminescence of 3200 °K.
7. The middle photoflood light was pointed at a 60-degree angle towards the ceiling to get a more uniform distribution of light across the entire image frame.

Table 4 shows the empirical data results obtained from Adobe's PhotoShop 4.0 for overall gray level intensity values and intensity values for the red, green and blue channels.

Table 4 - Results for Camera #1, Test #2

EV	Channel	TL	ML	BL	TR	MR	BR	100	105	110	115	120	125	130	135	140	145	150	155
-1.5	Intensity	44	44	41	46	44	41	36	40	43	44	43	48	50	52	51	54	56	59
	red	47	47	43	50	47	43	44	46	50	52	52	56	58	60	58	62	64	68
	green	44	44	40	45	44	40	32	35	38	40	40	44	46	48	47	50	52	56
	blue	37	37	33	39	37	33	36	38	42	44	40	44	48	50	48	50	54	56
-1	Intensity	52	50	46	52	52	46	42	44	48	50	50	56	60	62	60	64	68	72
	red	58	53	52	58	55	49	50	54	61	63	58	64	71	70	68	72	78	80
	green	51	50	45	51	52	46	38	40	42	44	46	51	54	58	56	60	64	68
	blue	43	43	39	45	45	39	38	44	48	46	50	52	56	62	56	60	66	68
-0.5	Intensity	62	62	54	64	62	54	48	54	58	60	62	68	72	76	74	80	84	88
	red	68	68	60	70	65	60	61	67	71	73	75	81	85	89	87	93	97	101
	green	61	61	53	63	62	53	42	48	52	54	56	62	66	70	68	74	78	82
	blue	51	51	47	57	55	47	48	54	58	60	60	66	70	72	72	76	82	84
0	Intensity	80	77	71	82	80	70	61	68	75	78	78	86	92	96	92	99	105	108
	red	86	84	76	88	86	76	75	81	89	93	93	101	107	109	107	113	119	121
	green	79	77	69	81	79	69	54	60	67	70	72	79	84	90	86	92	98	101
	blue	69	67	61	73	71	61	60	66	70	78	76	84	90	96	90	98	102	106
0.5	Intensity	96	96	86	98	98	86	76	84	90	96	96	104	110	114	112	118	122	128
	red	103	102	94	106	104	92	91	101	105	111	111	119	125	129	127	133	137	143
	green	95	95	85	97	97	85	68	75	82	88	88	97	102	106	104	110	115	120
	blue	85	85	75	87	87	75	76	84	90	96	94	104	110	114	110	114	122	128
1	Intensity	118	116	108	120	118	108	96	104	112	116	116	126	134	139	134	144	152	156
	red	124	122	114	128	124	116	112	122	130	134	134	144	152	157	152	159	168	173
	green	116	115	106	118	117	108	87	95	103	107	108	117	125	130	126	135	143	147
	blue	107	105	97	109	107	97	96	104	112	116	116	126	132	140	134	144	150	156
1.5	Intensity	140	140	128	146	144	130	116	126	136	140	142	154	162	168	164	172	180	182
	red	150	148	138	154	150	138	136	147	157	161	161	174	183	186	182	198	198	200
	green	138	139	126	143	143	128	105	115	124	129	132	145	151	159	155	163	169	173
	blue	129	129	117	133	133	119	116	126	135	141	143	154	162	168	164	172	180	182

Camera #1 Gray Background Test #3

As a result of the two tests using the twelve separate gray patches, it was found that it was difficult if not impossible to adjust the lighting to be completely uniform over the entire image area. Therefore, a third test was performed using a specially constructed single A4 sized sheet with the twelve gray patches, which was more the size of a human face. By using this methodology, a much more uniform distribution of lighting could be achieved over a much smaller area for the image. As with the twelve separate gray patches, each gray patch on this single sheet varied in gray level intensity values by 5 units ranging from 100 to 155 in gray level intensity. It should also be noted that the red,

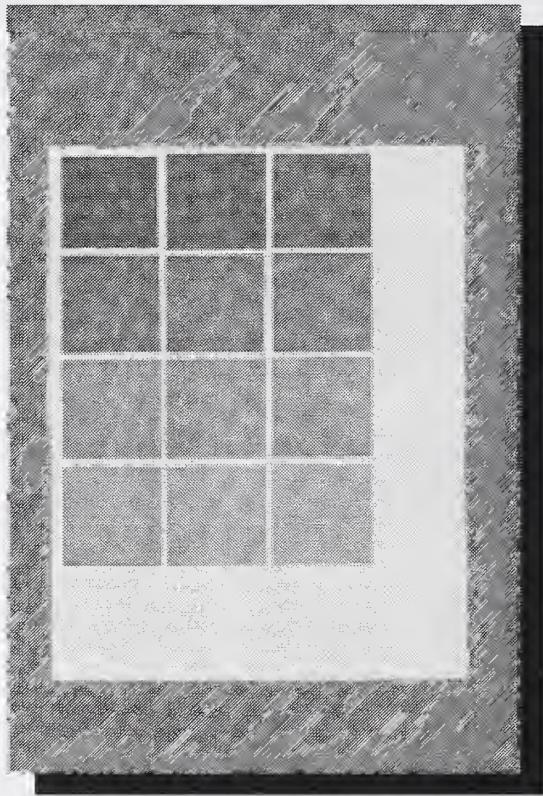


Figure 8 - Single Gray Sheet

green and blue channels were exactly the same as the gray level intensity values for each gray patch. Figure 8 is a picture of the single sheet of gray patches used from this point on in the experiment.

Table 5 gives the results of the Camera #1 ranging in EV values from 0.0 to 1.5

Table 5 - Results for Camera #1, Test #3

EV	Channel	TL	ML	BL	TR	MR	BR	100	105	110	115	120	125	130	135	140	145	150	155
0.0	Intensity	83	83	80	79	80	75	65	69	76	78	85	92	93	99	104	105	111	116
	red	82	82	80	78	79	75	74	77	84	86	92	99	100	105	110	111	116	121
	green	84	85	81	81	82	77	61	66	72	75	82	89	91	97	102	104	110	115
	blue	72	73	70	71	71	66	60	65	71	74	80	87	88	94	99	100	106	111
0.5	Intensity	101	102	98	95	98	93	82	87	94	97	105	111	113	118	124	126	132	139
	red	101	101	98	95	95	92	92	98	104	105	113	119	120	125	131	131	138	145
	green	103	104	100	98	100	94	79	83	90	94	101	109	110	116	122	124	131	138
	blue	90	91	87	86	87	82	77	82	89	91	99	106	107	113	119	120	127	133
1.0	Intensity	122	123	120	114	118	113	103	108	114	118	126	135	137	145	152	154	160	168
	red	123	123	121	115	118	113	117	122	127	130	138	147	148	156	163	163	169	177
	green	123	125	121	116	120	114	98	103	109	113	121	130	133	140	148	150	157	165
	blue	108	110	107	103	106	101	97	102	108	111	119	129	130	137	145	147	153	161
1.5	Intensity	149	153	146	139	146	138	128	135	144	148	158	167	169	177	182	182	187	192
	red	154	159	152	144	150	142	148	154	163	166	175	185	186	193	198	198	202	206
	green	148	154	146	139	147	138	120	126	135	141	151	160	162	170	175	176	181	186
	blue	134	138	130	126	132	120	120	127	136	140	149	159	161	168	174	175	178	183

Camera #2 Gray Background Tests

Using the same lighting configuration as described above for Camera #1 tests, Camera #2 with a pixel resolution setting of the maximum 1024 by 950 pixel resolution was used. Pictures were taken of the gray patch backdrop while varying the exposure setting from a minimum of -2 to a maximum of +2 in increments of 0.5 exposure steps. Table 6 below shows the values obtained when the resultant images were analyzed using the PhotoShop 4 software, and utilizing the histogram function for determining the overall gray level as well as the values for each of the RGB channels.

Table 6 - Results for Camera #2 Test

EV	Channel	TL	ML	BL	TR	MR	BR	100	105	110	115	120	125	130	135	140	145	150	155
-2	Intensity	52	50	46	52	52	46	42	44	48	50	50	56	60	62	60	64	68	72
	red	58	53	52	58	55	49	50	54	61	63	58	64	71	70	68	72	78	80
	green	51	50	45	51	52	46	38	40	42	44	46	51	54	58	56	60	64	68
	blue	43	43	39	45	45	39	38	44	48	46	50	52	56	62	56	60	66	68
-1.5	Intensity	62	62	54	64	62	54	48	54	58	60	62	68	72	76	74	80	84	88

AF	Channel	TL	ML	BL	TR	MR	BR	100	105	110	115	120	125	130	135	140	145	150	155
-1.0	red	68	68	60	70	65	60	61	67	71	73	75	81	85	89	87	93	97	101
	green	61	61	53	63	62	53	42	48	52	54	56	62	66	70	68	74	78	82
	blue	51	51	47	57	55	47	48	54	58	60	60	66	70	72	72	76	82	84
	Intensity	80	77	71	82	80	70	61	68	75	78	78	86	92	96	92	99	105	108
	red	86	84	76	88	86	76	75	81	89	93	93	101	107	109	107	113	119	121
	green	79	77	69	81	79	69	54	60	67	70	72	79	84	90	86	92	98	101
	blue	69	67	61	73	71	61	60	66	70	78	76	84	90	96	90	98	102	106
-0.5	Intensity	96	96	86	98	98	86	76	84	90	96	96	104	110	114	112	118	122	128
	red	103	102	94	106	104	92	91	101	105	111	111	119	125	129	127	133	137	143
	green	95	95	85	97	97	85	68	75	82	88	88	97	102	106	104	110	115	120
	blue	85	85	75	87	87	75	76	84	90	96	94	104	110	114	110	114	122	128
0.0	Intensity	118	116	108	120	118	108	96	104	112	116	116	126	134	139	134	144	152	156
	red	124	122	114	128	124	116	112	122	130	134	134	144	152	157	152	159	168	173
	green	116	115	106	118	117	108	87	95	103	107	108	117	125	130	126	135	143	147
	blue	107	105	97	109	107	97	96	104	112	116	116	126	132	140	134	144	150	156
0.5	Intensity	140	140	128	146	144	130	116	126	136	140	142	154	162	168	164	172	180	182
	red	150	148	138	154	150	138	136	147	157	161	161	174	183	186	182	198	198	200
	green	138	139	126	143	143	128	105	115	124	129	132	145	151	159	155	163	169	173
	blue	129	129	117	133	133	119	116	126	135	141	143	154	162	168	164	172	180	182
1.0	Intensity	140	140	128	146	144	130	116	126	136	140	142	154	162	168	164	172	180	182
	red	150	148	138	154	150	138	136	147	157	161	161	174	183	186	182	198	198	200
	green	138	139	126	143	143	128	105	115	124	129	132	145	151	159	155	163	169	173
	blue	129	129	117	133	133	119	116	126	135	141	143	154	162	168	164	172	180	182
1.5	Intensity	140	140	128	146	144	130	116	126	136	140	142	154	162	168	164	172	180	182
	red	150	148	138	154	150	138	136	147	157	161	161	174	183	186	182	198	198	200
	green	138	139	126	143	143	128	105	115	124	129	132	145	151	159	155	163	169	173
	blue	129	129	117	133	133	119	116	126	135	141	143	154	162	168	164	172	180	182
2.0	Intensity	140	140	128	146	144	130	116	126	136	140	142	154	162	168	164	172	180	182
	red	150	148	138	154	150	138	136	147	157	161	161	174	183	186	182	198	198	200
	green	138	139	126	143	143	128	105	115	124	129	132	145	151	159	155	163	169	173
	blue	129	129	117	133	133	119	116	126	135	141	143	154	162	168	164	172	180	182

Camera #3 Gray Background Test with Flood Lamps

Again, using the same lighting configuration as described for both Camera #1 and Camera #2 tests, Camera #3 with a pixel resolution of 1500 by 1200 was used. Pictures were taken of the gray patch backdrop while varying the exposure setting manually by using a combination of shutter speed and f-stop until the 125-gray patch had a value close

to 125 as possible without changing the lighting configuration. The table below shows the values obtained when the resultant images were analyzed using the PhotoShop 4 software, and utilizing the luminosity histogram function for determining the overall gray level as well as the values for each of the RGB channels.

Table 7 - Results for Camera #3 Test

AF	Channel	TL	ML	BL	TR	MR	BR	1/100	1/130	1/160	1/200	1/250	1/300	1/400	1/500	1/600	1/800		
1/125	Intensity	65	66	60	55	55	52	50	54	61	63	72	78	78	87	91	90	97	103
	red	69	71	65	60	62	57	63	68	74	74	85	93	91	101	105	102	110	115
	green	65	65	60	54	54	50	45	49	55	58	66	72	72	81	85	84	92	98
	blue	58	56	51	47	47	44	48	52	60	61	67	74	75	82	86	85	92	97
1/30	Intensity	125	120	122	122	119	121	99	104	109	115	120	128	132	138	144	148	154	161
	red	158	147	151	156	144	149	131	135	142	149	155	162	168	173	180	184	191	198
	green	108	106	107	104	105	106	82	86	91	96	100	109	113	118	123	128	134	140
	blue	127	125	123	126	126	124	109	115	119	123	129	136	140	146	152	157	163	171

We observed from Table 7 above that the exposure setting of 1/125 sec at F4 with the photo lamps in the same position as in the other camera tests was not sufficient for obtaining the correct gray readings. However, the shutter setting of 1/30 sec most closely matched the gray calibration sheet. Notice that the overall illumination measurements came very close to the actual numbers. It was further observed that the red channel gave much higher readings than either the green or the blue channels. We also observed that the blue channel came closest to the overall illumination readings. The net result was that the image appeared to have a red bias, which to the eye appeared to be tinted pink.

When comparing camera #3 with both camera #2 and camera #1 , it was evident that the exposure could be more tightly controlled through the use of both aperture settings and shutter speed settings. However, the other two cameras could only be controlled through the one overall EV setting. When using Camera #3, the only way to achieve close approximations to the gray calibration sheet would be to use a filter that would align the red channel to the other two color channels, thus eliminating the red bias.

Subject Exposure Tests

The objective of the "variation in clothing" tests were to show how the individual cameras reacted in exposure compensation to subjects wearing black clothing compared to subjects wearing lighter clothing. Even though each camera was first calibrated to the 18% gray background using a given photo flood lighting situation, the subject's clothing

made a difference in exposure for both the camera #1, camera #2, and the automatic setting on camera #3. The electronic circuitry within each of those cameras compensated for the variance in clothing thus producing the effect of changing the gray level values in the gray background. Unfortunately, neither camera #1 or camera #2 had any manual override settings that would keep the background exposure constant. Only camera #3 had the capability to override the electronic compensating factors due to a variance in clothing.

There were three series of tests performed; i.e., one test for each of the three cameras. The gray level values for each of these tests are shown in Tables 9, 10, and 11.

1. Camera #1 Clothing Test

The gray background was first shot at an EV 0.0 setting without a subject in the frame. The gray level value for the gray background image yielded a measurement of 118 with the PhotoShop luminosity histogram function. Then the subject was introduced to the frame wearing samples of light and black clothing. The results are shown in Table 8 for camera #1. In all instances with the subject in the frame, the measured luminescence of the background was lighter than when there was no subject in the frame. Furthermore, the black clothing produced still lighter measurements than the lighter clothing.

Table 8 - Camera #1 Clothing Test Results with EV = 0.0

Test	Gray Level Value
Subject 1 - light shirt	122
Subject 1 - Black shirt	134
Subject 2 - light shirt	126
Subject 2 - Black Shirt	133
Gray Background itself	118

2. Camera #2 Clothing Test

The above test was repeated using camera #2. Camera #2 was set at an EV value of 1.0 to obtain measurements in the range of 110 to 130 for the gray background. The results as shown in Table 9 were very similar to the camera #1 clothing test, i.e., the subjects wearing black measured the highest values for the gray background.

Table 9 - Camera #2 Clothing Test Results

Test	Gray Level Value
Subject 1 - light shirt	119
Subject 1 - Black shirt	136
Subject 2 - light shirt	115
Subject 2 - Black Shirt	129
Gray Background itself	113

3. Camera #3 with Manual Settings

The same test was again repeated for camera #3. The camera was set at 1/30 sec with an aperture setting of f4.5. Also, the ASA setting was at 400. The gray background image was measured at 124, which just about matched the value of the Kodak gray card. The results (Table 10) of this test were different from the tests with the other two cameras. The subjects with the light colored shirts yielded a measured background value below the background image value, but the black shirt value was in concordance with the other two cameras. The variance only indicates a difference in sensitivities of the light metering system of camera #3 when compared with both camera #1 and camera #2.

Table 10 - Camera #3 Clothing Test Results

Test	Gray Level Value
Subject 1 - light shirt	104
Subject 1 - Black shirt	135
Subject 2 - light shirt	116
Subject 2 - Black Shirt	130
Gray Background itself	124

Obtained Results

Camera #1, Test 1 Results:

The twelve separate gray patch photoflood test showed the following results:

1. The illumination of the background was uneven, especially with the gray level intensity values taken at the top of the frame when compared with values taken at the bottom of the frame. Also, the values on the right side were higher than the values on the left side. Detailed data is available upon request.
2. Values were then plotted for the gray level values taken inside of each gray patch. The significant points to be made from these plots are as follows:

- Camera #1 showed a definite red bias as indicated by the constantly higher values obtained for the red channel. This indicates that the recorded gray surfaces had a slightly reddish tint.
- The blue channel was measured to be the closest to the values obtained for the overall gray level intensity values.
- The green channel was measured to be slightly lower in values than both the red and blue channels.
- From the tests taken with the densitometer, it was shown that the gray patch with the intensity value of 125 most closely matched the Kodak Gray Card by having a density value of 0.76 (the Kodak card had a density value of 0.75). Therefore, the camera #1, Test #1 results showed that the set of values for EV setting of 1.0 were the closest to the 18% gray requirement; i.e., the values obtained for the "125 intensity gray patch" were 124 for overall gray level intensity and 140, 116, and 125 for RGB respectively.
- As the EV setting was increased to the maximum exposure of 1.5 the red channel was very exaggerated when compared to the other EV settings. The blue channel was still the best in following the overall gray level values.

Camera #1, Test 2 Results:

These results were not significantly different from the results obtained for camera #1, test #1. When comparing the results between camera #1, test #1 and camera #1, test #2, one can deduce that the lighting was much more uniform in the camera #1, test 2 but still uneven from top to bottom.

Camera #2 Test Results

Camera #2 test used the same lighting setup as in the camera #1 tests. The single sheet of twelve gray patches was used, since it rendered a much more uniform lighting situation. Images were produced varying the camera EV settings from -2 to +2 in increments of 0.5. The best results were achieved at EV 0 setting as shown in Table 6 above. The overall intensity for the "125" gray patch was measured to be 126. The blue channel was also measured to be 126. The red channel was much higher and the green channel was a little lower. It was clearly evident that the camera had a red bias as seen from the obtained measurements.

Conclusions and Inferences

The following points are made from the review of tests and associated cameras used in the experiments:

1. When calibrating a camera to match the 18% gray backdrop, the use of a single sheet with gray patches should be employed so that the lighting will be uniformly distributed over the entire surface.
2. Exposure compensations should be made for individual subject conditions of clothing, skin texture hair coloring, etc.

3. Digital camera models that do not have manual exposure override features are less adaptable for the mug shot process.
4. Cameras having manual controls should be used in order to get a uniform exposure values for the gray background.
5. Subjects wearing different colored clothing will affect the outcome of the exposure on automatically controlled digital cameras.
6. As the exposure setting is increased to the maximum, the variance between the red, blue and green channels is exaggerated, thus making the gray background look tinted in nature. Use enough lighting to be able to set the camera at the 0.0 exposure setting and still obtain an 18% gray rendering of the background.

